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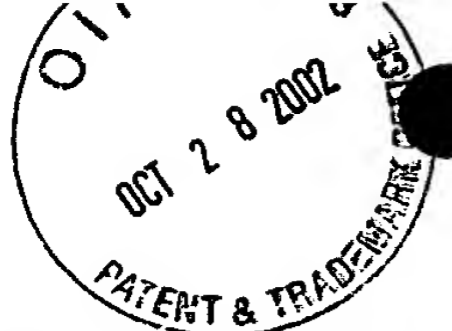
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English Translation of  
Applicants' Priority Document:  
Japanese Patent App. No. 11-162792

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[Prepayment Register Number] 007537  
[Amount of Payment] 21,000 yen  
[List of Submitted Documents]  
[Name of Document] Specification 1  
[Name of Document] Drawings 1  
[Name of Document] Abstract 1



[Name of Document] Specification

[Title of the Invention] Semiconductor Laser Device

[Claims]

[Claim 1] A semiconductor laser device for oscillating within  
5 a wavelength band of  $1.1 \mu\text{m}$  or less, comprising a  
semiconductor laminated structure including an active layer  
of a quantum well structure, a low-reflection film formed on  
one end face of the structure, and a high-reflection film  
formed on the other end face of the structure, wherein a  
10 cavity length is  $1,200 \mu\text{m}$  or more.

[Claim 2] The semiconductor laser device according to claim 1,  
wherein the low-reflection film has a reflectance of 5% or  
less.

[Claim 3] The semiconductor laser device according to claim 1  
15 or 2, wherein the active layer is formed of one or two  
quantum well structures.

[Detailed Description of the Invention]

[0001]

[Technical Field to Which the Invention Belongs]

20 The present invention relates to a semiconductor laser  
device, more particularly, to a semiconductor laser device  
which requires high optical output of hundreds of mW, such as  
a gain waveguide laser device that oscillates with a  
relatively short wavelength of  $1.1 \mu\text{m}$  or less, for instance,  
25  $0.98 \mu\text{m}$ , which assures linearity in current-optical output  
characteristic even at the time of high-current operation,  
and which is useful as a pumping light source for an optical  
fiber amplifier.

[0002]

30 [Prior Art]

In a semiconductor laser device having an active layer  
(light emission region) formed of a quantum well structure,  
injected carriers are quantized toward quantum wells, and the  
state density of carrier energy forms a stepped pattern.

Accordingly, the gain coefficient rapidly rises in response to a driving current, so that a laser beam can be oscillated even with use of a low threshold current density. The semiconductor laser device of such a gain wavelength type  
5 delivers higher optical output than a semiconductor laser device having an active layer of a bulk semiconductor, and therefore it has been studied for practical use as a pumping light source for an optical fiber amplifier.

[0003]

10 For instance, the semiconductor laser device as described below, which oscillates with a wavelength of 0.98  $\mu\text{m}$ , has been studied as the pumping light source for the optical fiber amplifier.

Fig. 4 shows a side view of the semiconductor laser  
15 device, and Fig. 5 is a sectional view taken along line V-V of Fig. 4.

[0004]

The device A has a semiconductor layer structure, including a lower clad layer 2 of n-AlGaAs, an active layer 3  
20 of a quantum well structure of InGaAs and GaAs, an upper clad layer 4 of p-AlGaAs, and a cap layer 5 of p-GaAs, which are stacked in layers on an n-GaAs substrate 1. Part of the upper clad layer 4 and the cap layer 5 form a mesa structure, and a passivation film 6 of SiN is formed on the lateral of  
25 the mesa structure. An upper electrode 7 of Ti/Pt/Au is formed on the cap layer 5 and the passivation film 6, and a lower electrode 8 of AuGe/Ni/Au is formed on the back surface of the substrate 1.

[0005]

30 The device A, of which the aforementioned layer structure is formed on the n-GaAs substrate by, for instance, MOCVD method, is cleft with a given cavity length L. A low-reflection film 9 of, for example, SiN is formed on one end face  $S_1$  of the structure, and a high-reflection film 10 of,

for example,  $\text{SiO}_2/\text{Si}$  is formed on the other end face  $S_2$ .

In the case of the device A with the structure, it is considered that high optical output can be effectively obtained by increasing the cavity length  $L$ . This is because  
5 an increase in cavity length enables the injection of a large driving current even with the same threshold current density and the reduction of the influence of heat, and thus high optical output can be expected. If the cavity length is too long, however, the differential quantum efficiency of the  
10 device A lowers, which causes a problem that a higher current is required for high optical output operation. Therefore, the cavity length of the device A with this structure is so designed as not to exceed  $1,000 \mu\text{m}$ .

[0006]

15 [Problems That the Invention is to Solve]

The inventors hereof examined the current-optical output characteristic of the device A with the layer structure shown in Figs. 4 and 5 wherein the cavity length  $L$  was adjusted to  $1,000 \mu\text{m}$ . Obtained through the examination were the  
20 characteristic curve as shown in Fig. 6 and the following new knowledge.

As is obvious from Fig. 6, when a driving current ( $A_1$ ) of about 200 mA was injected, a first kink ( $a_1$ ) was generated in the optical output, and a linear relation between the  
25 driving current and the optical output disappeared. When the driving current was further increased to a level ( $A_2$ ) of about 500 mA, a second kink ( $a_2$ ) was generated in the optical output. In other words, in the case of the device A, the two kinks  $a_1$  and  $a_2$  were generated in the current-optical output  
30 characteristic curve as the driving current was increased.

[0007]

Accordingly, the inventors hereof first closely examined the oscillation spectrum of the device A. Results of the examination are described below.

(1) Fig. 7 shows the oscillation spectrum.

As is clear from the oscillation spectrum, there are a small number of longitudinal oscillation modes which exist in a gain band  $g$ . Intervals between the oscillation  
5 longitudinal modes are wide, and the intensity of a central longitudinal oscillation mode  $B_0$  is 5 dB or more higher than those of side modes  $B_1$  and  $B_2$ . As a whole, single longitudinal mode oscillation prescribed by the central longitudinal oscillation mode  $B_0$  is dominant.

/0 [0008]

(2) The oscillation spectrum, which was obtained when the first kink ( $a_1$ ) was generated, indicates that the gain band as a whole shifts to a longer wavelength side by about 0.4 nm, and that the central longitudinal oscillation mode  $B_0$   
/5 jumps to the adjacent side mode  $B_2$ .

Knowledge described in (1) can be explained by the fact that the device A is of a gain waveguide type, which oscillates within a short wavelength band of 0.98  $\mu\text{m}$ .  
[0009]

20 Generally, the probability of generation of single longitudinal mode oscillation is related to a spontaneous emission factor ( $\beta_{\text{sp}}$ ) given by

$$\beta_{\text{sp}} = \Gamma \cdot \lambda^4 \cdot K / 4\pi^2 \cdot n^3 \cdot V \cdot \delta\lambda \quad \cdots (1)$$

(where  $\Gamma$  is a confinement coefficient of the active  
25 layer,  $\lambda$  is an oscillation wavelength,  $K$  is a factor reflective of the complexity of a traverse mode,  $n$  is an equivalent refractive index,  $V$  is the volume of the active layer, and  $\delta\lambda$  is the width of the spectrum.) It is believed that the smaller the value  $\beta_{\text{sp}}$  is, the higher the probability  
30 of generation of single longitudinal mode oscillation is.  
[0010]

In the case of the device A, therefore, the oscillation wavelength ( $\lambda$ ) is as short as 0.98  $\mu\text{m}$ , so that  $\beta_{\text{sp}}$  is lowered in proportion to the fourth power of  $\lambda$ . Accordingly, the

device A is supposed to be able to cause single longitudinal mode oscillation with a high probability.

However, if a module is constructed in a manner such that the device which undergoes single longitudinal mode oscillation is connected to an optical fiber, the following problem arises. A laser beam generated by single longitudinal mode oscillation has its noise properties lowered under the influence of return light from an end portion of the optical fiber. Further, the oscillation of the laser beam is made unstable by the return light. Therefore, an optical output fetched from the module and a monitor current are rendered unstable.

[0011]

In order to heighten the reliability of the device A as a pumping light source for an optical fiber amplifier, it is necessary to solve the above problem that is attributable to single longitudinal mode oscillation.

The result (2) implies the following situation. In consideration of great gain differences caused between the longitudinal modes for single longitudinal mode oscillation, the occurrence of the longitudinal mode hopping indicates that optical output discontinuously fluctuates on a large scale. Therefore, it can be considered that when the injected current almost reaches the level  $A_1$ , the current-optical output characteristic loses its linearity, so that the first kink ( $a_1$ ) is generated.

[0012]

In the next place, the inventors hereof observed a far field pattern of the device A and obtained the findings as shown in Fig. 8.

In Fig. 8, the curve  $C_1$  represents a transverse oscillation mode for the case where the injected current is lower than  $A_2$ , and the curve  $C_2$  represents a transverse oscillation mode for the case where the injected current is

near  $A_2$  (or where the second kink  $a_2$  is generated).

[0013]

As is apparent from Fig. 8, when the injected current increases to  $A_2$ , unimodal transverse oscillation modes shift  
5 horizontally from the center position of the device A. That is, the direction of emission of the laser beam changes.

For this reason, if the module is constructed by connecting an optical fiber to the device A, the optical output fetched through the optical fiber fluctuates when the  
10 injected current reaches a value close to  $A_2$ . This is considered to result in the generation of the second kink ( $a_2$ ) in the current-optical output characteristic curve.

[0014]

An object of the present invention is to provide a novel  
15 semiconductor laser device of the gain waveguide type, which has been developed on the basis of the above new knowledge associated with the device A that oscillates with a short wavelength band of  $0.98 \mu\text{m}$ , the novel semiconductor laser device, being capable of oscillating without generating any  
20 kinks in a current-optical output characteristic curve even with use of the injected current of 500 mA or more, and having a high reliability as a pumping light source for an optical fiber amplifier.

[0015]

## 25 [Means to Achieve the Object]

The inventors hereof conducted the following examinations in the process of study to achieve the above object.

(1) First, single longitudinal mode oscillation occurs  
30 with a high probability in the case of a semiconductor laser device of the gain wavelength type which oscillates in a short-wavelength band of about  $0.98 \mu\text{m}$ . Intervals between longitudinal modes are wide, and when the injected current increases, the longitudinal mode hopping occurs, which causes

substantial fluctuations of the optical output. This results in the emergence of a first kink ( $a_1$ ) in a current-optical output characteristic curve.

It is known that the intervals between the longitudinal  
5 modes are proportional to the reciprocal of the cavity length ( $L$ ) of the device. Therefore, the intervals between the longitudinal modes can be shortened by increasing the cavity length ( $L$ ) of the device, so that the fluctuations of the optical output caused by the hopping of the longitudinal  
10 modes can be reduced.

[0016]

(2) A shift of transverse oscillation modes that causes a second kink ( $a_2$ ) can be regarded as a phenomenon that takes place from the following cause. By injecting a high current  
15 into the device, the resistance heating of the device (cavity) is increased, resulting in the change of the refractive index of each semiconductor layer and a subsequent change of a confinement effect on a laser beam in the horizontal direction.

20 Accordingly, in order to prevent the generation of the second kink, it may be advisable to design the device (cavity) so that its resistance heating is small even when the high current is injected therein. To that end, it is necessary that the cavity length of the device be increased  
25 to lower the resistance of the device.

[0017]

(3) In this case, although the increase in cavity length ( $L$ ) of the device lowers the light emission efficiency, this can be avoided by using a low-reflection surface for the  
30 light-emitting surface of the device.

[0018]

In consideration of these circumstances, the inventors hereof examined the current-optical output characteristic of the device A with its cavity length ( $L$ ) varied. Thereupon,

the inventors found that the linearity of the current-optical output characteristic curve can be secured by adjusting the cavity length (L) to a value not smaller than the value mentioned later, and they developed the semiconductor laser  
5 device according to the present invention.

According to the present invention, there is provided a semiconductor laser device for oscillating within a wavelength band of 1.1  $\mu\text{m}$  or less, comprising a semiconductor laminated structure including an active layer formed of a  
10 quantum well structure, a low-reflection film formed on one end face of the structure, and a high-reflection film formed on the other end face of the structure, wherein a cavity length is 1,200  $\mu\text{m}$  or more.

[0019]

15 Preferably, the low-reflection film of the semiconductor laser device has a reflectance of 5% or less and the active layer is formed of one or two quantum well structures.

[0020]

[Embodiments of the Invention]

20 A device according to the present invention will now be described with reference to a device A with a layer structure shown in Figs. 4 and 5.

The device of the invention has a layer structure such that a semiconductor material is put on a semiconductor  
25 substrate by, for example, MOCVD method, and an active layer 3 has a quantum well structure. InP- and GaInNAs-based semiconductor materials may be used in place of the aforementioned materials for the device A.

[0021]

30 The most distinguishing feature of the device of the invention lies in cavity length (L) being 1,200  $\mu\text{m}$  or more.

If the cavity length (L) is increased, intervals between longitudinal oscillation modes existing in a gain band of an oscillation spectrum are shortened in proportion to the

reciprocal of the cavity length, as mentioned before. For instance, if the cavity length (L) is 1,200  $\mu\text{m}$  or more, and the quantum well structure is formed of InGaAs/GaAs, the intervals between the longitudinal oscillation modes are  
5 about 0.12 nm each. The oscillation spectrum shows a longitudinal multi-oscillation mode in which a large number of longitudinal oscillation modes aggregate densely at short intervals in the gain band.

[0022]

10 Therefore, in the case of a module formed by connecting an optical fiber to the device, return light from the optical fiber is also in the longitudinal multi-mode, so that oscillation of a laser beam can be restrained from being made unstable by the return light.

15 Moreover, in this longitudinal multi-oscillation mode, gain differences between the longitudinal modes are so minor that fluctuations of the optical output are small even if a longitudinal mode hopping occurs. In consequence, the first kink ( $a_1$ ) ceases to be generated in the current-optical  
20 output characteristic.

[0023]

In order to stabilize such a longitudinal multi-oscillation mode, the volume of the active layer formed of the quantum well structure may preferably be reduced. More  
25 particularly, it is advisable to use one or two quantum well structures to form the active layer.

If the volume of the active layer is reduced, the value  $\beta_{\text{sp}}$  in the expression (1) becomes greater, which restrains single longitudinal mode oscillation. The decrease in the  
30 volume of the active layer lessens an internal loss of the cavity, so that the optical output can be improved.

[0024]

If the cavity length (L) is 1,200  $\mu\text{m}$  or more, the volume resistance of the cavity is lowered. Therefore, even if the

injected current is increased, the temperature of the active layer is restrained from rising, thereby securing a laser beam confinement effect. In consequence, displacement of transverse oscillation modes, which occurs with conventional devices, does not take place. Thus, the second kink ( $a_2$ ) cannot be generated in the current-optical output characteristic.

[0025]

As described above, in the case of the device according to the present invention, by adjusting the cavity length ( $L$ ) to 1,200  $\mu\text{m}$ , the kinks  $a_1$  and  $a_2$  can be prevented from being generated in the current-optical output characteristic curve, and therefore, the linearity of the curve can be maintained.

However, since the increase of the cavity length ( $L$ ) results in a decline of the light emission efficiency, a low-reflection film may preferably be formed on one end face of the cavity in the device of the invention.

[0026]

More specifically, a low-reflection film with a reflectance of 5% or less is formed on the one end face of the cavity, and a high-reflection film with a reflectance of 80% or more on the other end face.

[0027]

[Examples]

A lower clad layer 2 of n-AlGaAs with a thickness of 2  $\mu\text{m}$ , an active layer 3 formed of two quantum well structures of InGaAs and GaAs, an upper clad layer 4 of p-AlGaAs with a thickness of 2  $\mu\text{m}$ , and a cap layer 5 of p-GaAs with a thickness of 0.3  $\mu\text{m}$  were successively stacked in layers by MOCVD method on the (100) surface of a substrate 1 of n-GaAs. Thereafter, the upper part of the resulting layer structure was formed into a mesa structure of 4  $\mu\text{m}$  wide and 2  $\mu\text{m}$  high, and its whole surface was coated with a passivation film 6 of SiN. The back surface of the substrate 1 was polished so

that the thickness of the substrate was about 100  $\mu\text{m}$ . After the passivation film 6 on the upper surface of the cap layer 5 was removed, an upper electrode 7 of Ti/Pt/Au was formed on the surface of the resulting structure, and a lower electrode 8 of AuGe/Ni/Au was formed on the back surface of the substrate 1 to obtain the layer structure shown in Fig. 5.

[0028]

After the substrate was then cleft into bars with different cavity lengths (L), a low-reflection film 9 of SiN with a reflectance of 2% was formed on one end face  $S_1$  of each bar, and a high-reflection film 10 of  $\text{SiO}_2/\text{Si}$  with a reflectance of 95% was formed on the other end face  $S_2$ . Finally, the bars were worked into chips, whereupon devices, such as the one shown in Fig. 4, were obtained.

In respect to each of the obtained devices, intensity of the injected current (hereinafter referred to as kink current) to generate a kink was measured. The results are shown in Fig. 1 as a relation between the kink current and the cavity length (L) of the device.

[0029]

As is clear from Fig. 1, when the cavity length (L) of the device is adjusted to 800  $\mu\text{m}$  or more, the kink current is linearly increased. Especially, when the cavity length (L) is set to 1,200  $\mu\text{m}$  or more, the kink is not generated in the device even if an injected current is increased to several hundreds of mA, with which the device of the present invention is intended to operate.

Fig. 2 shows an oscillation spectrum of the device in which the cavity length (L) was set to 1,500  $\mu\text{m}$  and into which a current of 200 mA was injected.

[0030]

As is obvious from Fig. 2, the device shows a longitudinal multi-oscillation mode in which a large number of longitudinal modes exist at short intervals within the

gain band  $g$ . The intervals between the longitudinal modes are about 0.1 nm each.

Further, Fig. 3 shows the current-optical output characteristic curve of the device.

5 As clearly shown in Fig. 3, no kink is generated in the device until the injected current reaches 700 mA, and the linearity of the current-optical output characteristic is secured.

[0031]

10 In the case of this device (with a cavity length of 1,500  $\mu\text{m}$ ), the light emission efficiency thereof shows as good a value as 1 W/A, and the driving voltage is 2 V when the injected current is 500 mA. Also, the heating of the active layer is restrained, and there is no displacement of a  
15 transverse mode.

[0032]

[Advantages of the Invention]

As is clear from the above explanation, the semiconductor laser device of the gain waveguide type  
20 according to the present invention is capable of longitudinal multi-mode oscillation. Where the device is connected with an optical fiber to constitute a module, the adverse effect caused by return light is restrained, and the displacement of the transverse mode in the far field pattern does not occur,  
25 thus suppressing fluctuations of the optical output to be fetched. Consequently, as a whole, the linearity of the current-optical output characteristic can be secured even if the injected current is increased.

[0033]

30 Therefore, the device according to the present invention has a significant industrial value as a pumping optical source for an optical fiber amplifier.

[Brief Description of the Drawings]

[FIG. 1]

A graph showing a relation between a cavity length and a kink current.

[FIG. 2]

5 A diagram showing an oscillation spectrum of a device according the present invention wherein the cavity length is 1,500  $\mu\text{m}$ .

[FIG. 3]

A diagram showing a current-optical output characteristic of the device according to the present  
10 invention wherein the cavity length is 1,500  $\mu\text{m}$ .

[FIG. 4]

A side view of a laser device A of a gain waveguide type.

[FIG. 5]

A cross-sectional view taken along line V-V in Fig. 4.

15 [FIG. 6]

A diagram showing a current-optical output characteristic of the device A (with a cavity length of 1,000  $\mu\text{m}$ ) shown in Fig. 4.

[FIG. 7]

20 A diagram showing an oscillation spectrum of the device shown in Fig. 4.

[FIG. 8]

A graph showing a transverse mode in a far field pattern of the device shown in Fig. 4.

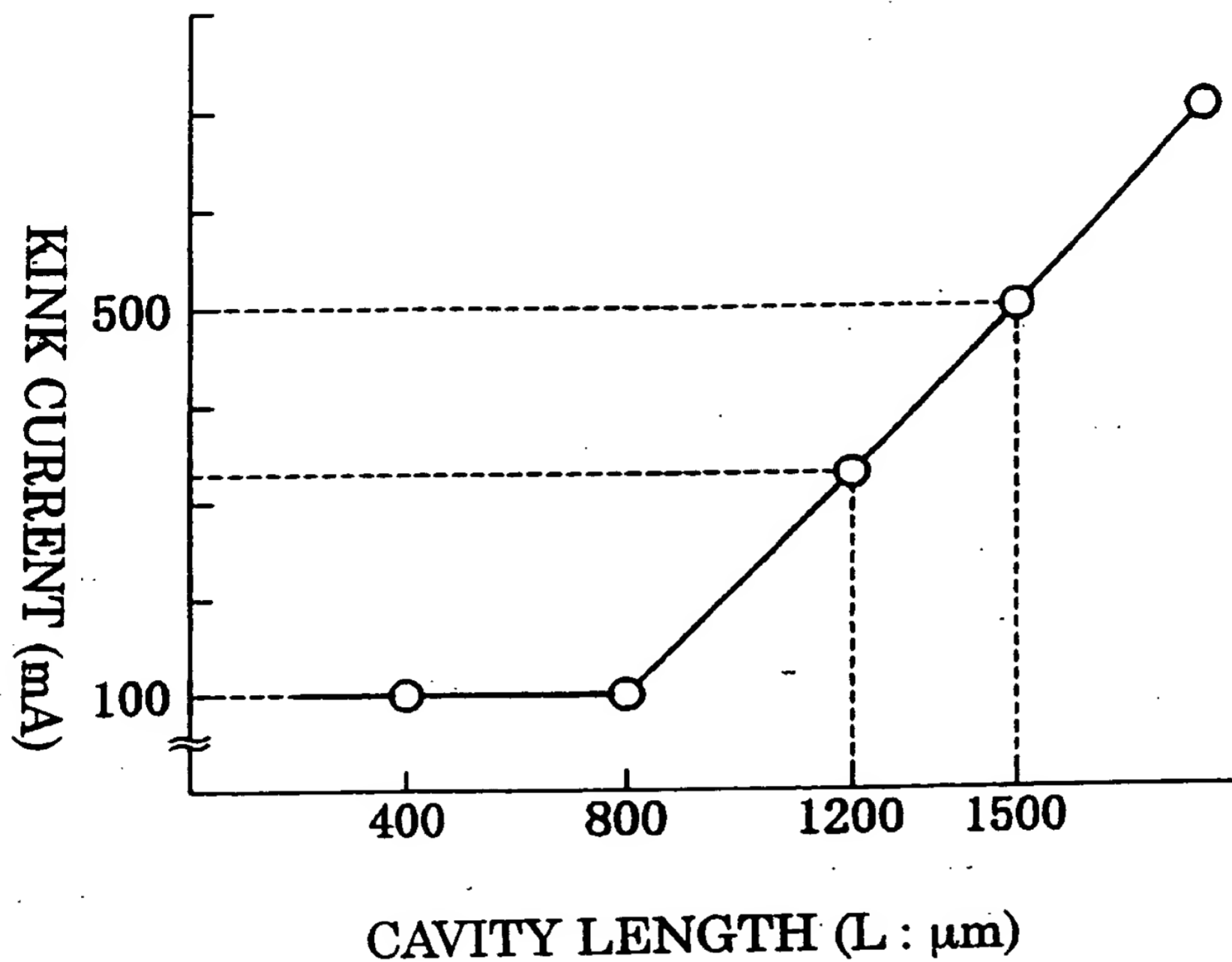
25 [Explanation of Reference Numerals]

- 1 n-GaAs substrate
- 2 n-AlGaAs layer (lower clad layer)
- 3 quantum well structure (active layer) of AlGaAs/GaAs
- 4 p-AlGaAs layer (upper clad layer)
- 30 5 p-GaAs layer (cap layer)
- 6 passivation film of SiN
- 7 upper electrode
- 8 lower electrode
- 9 low-reflection film

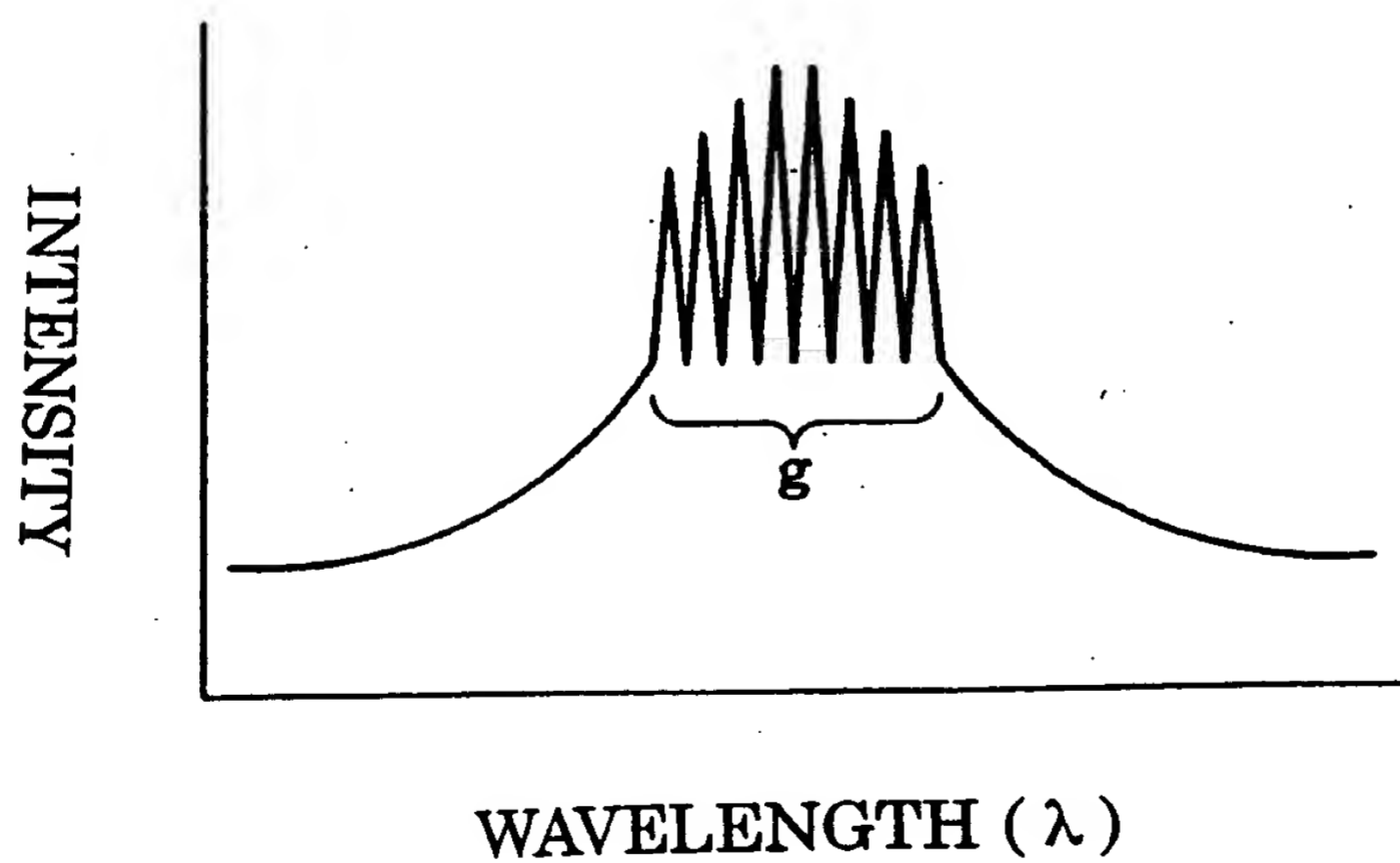
10 high-reflection film

[Name of Document] Drawings

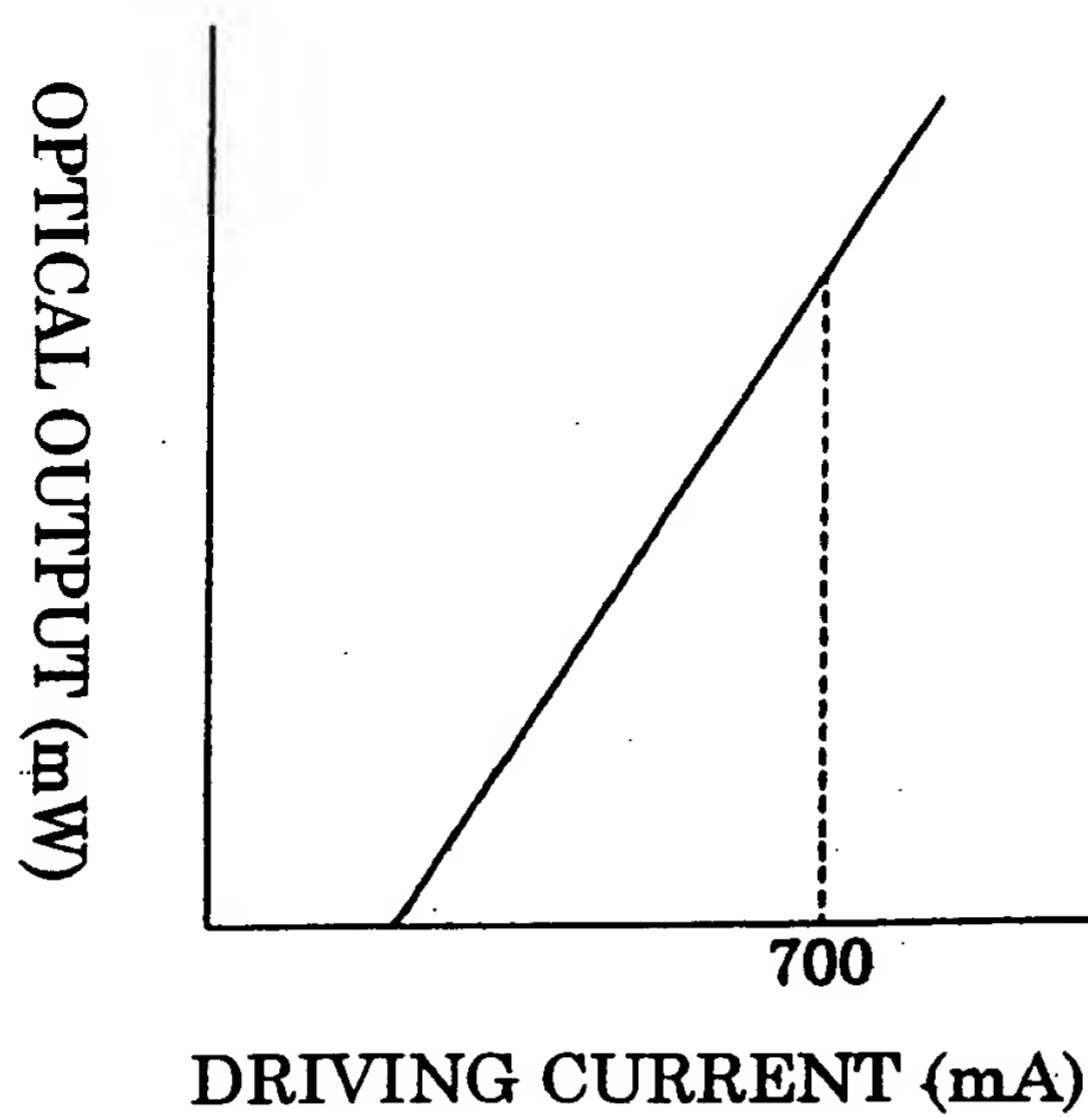
[FIG. 1]



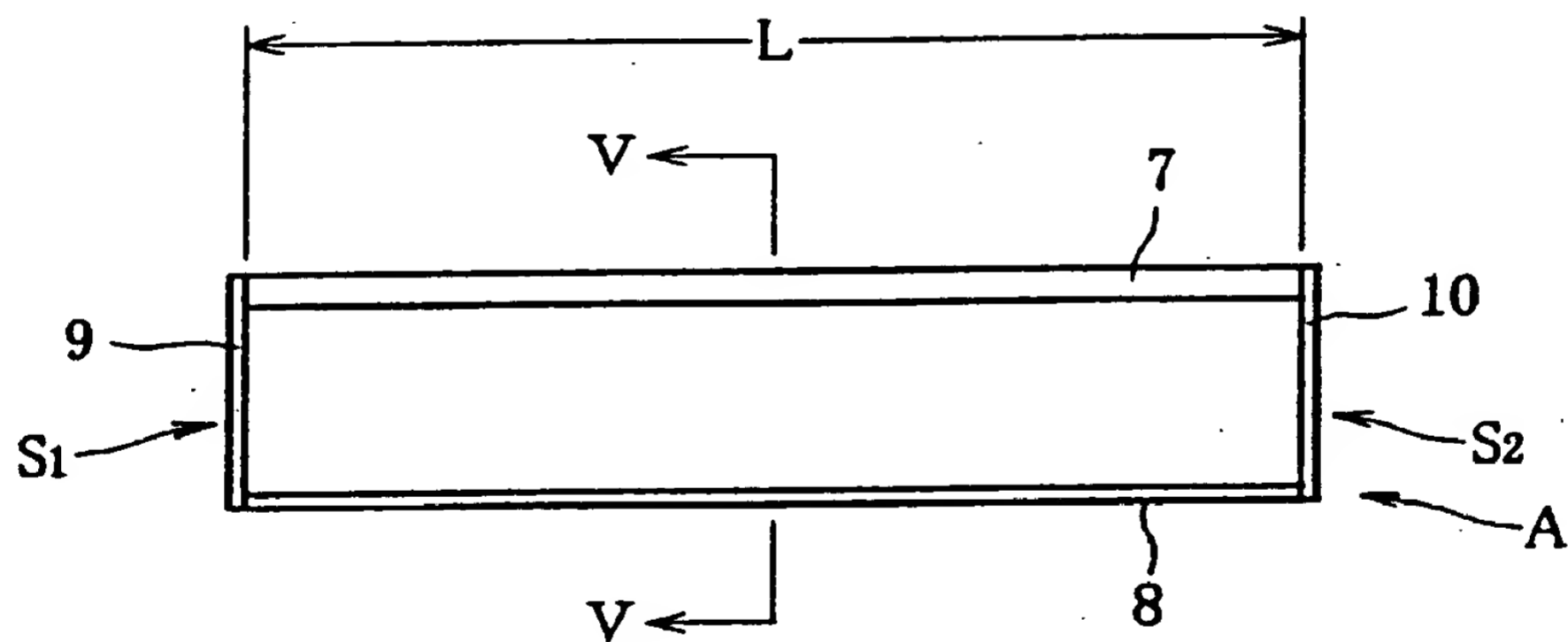
[FIG. 2]



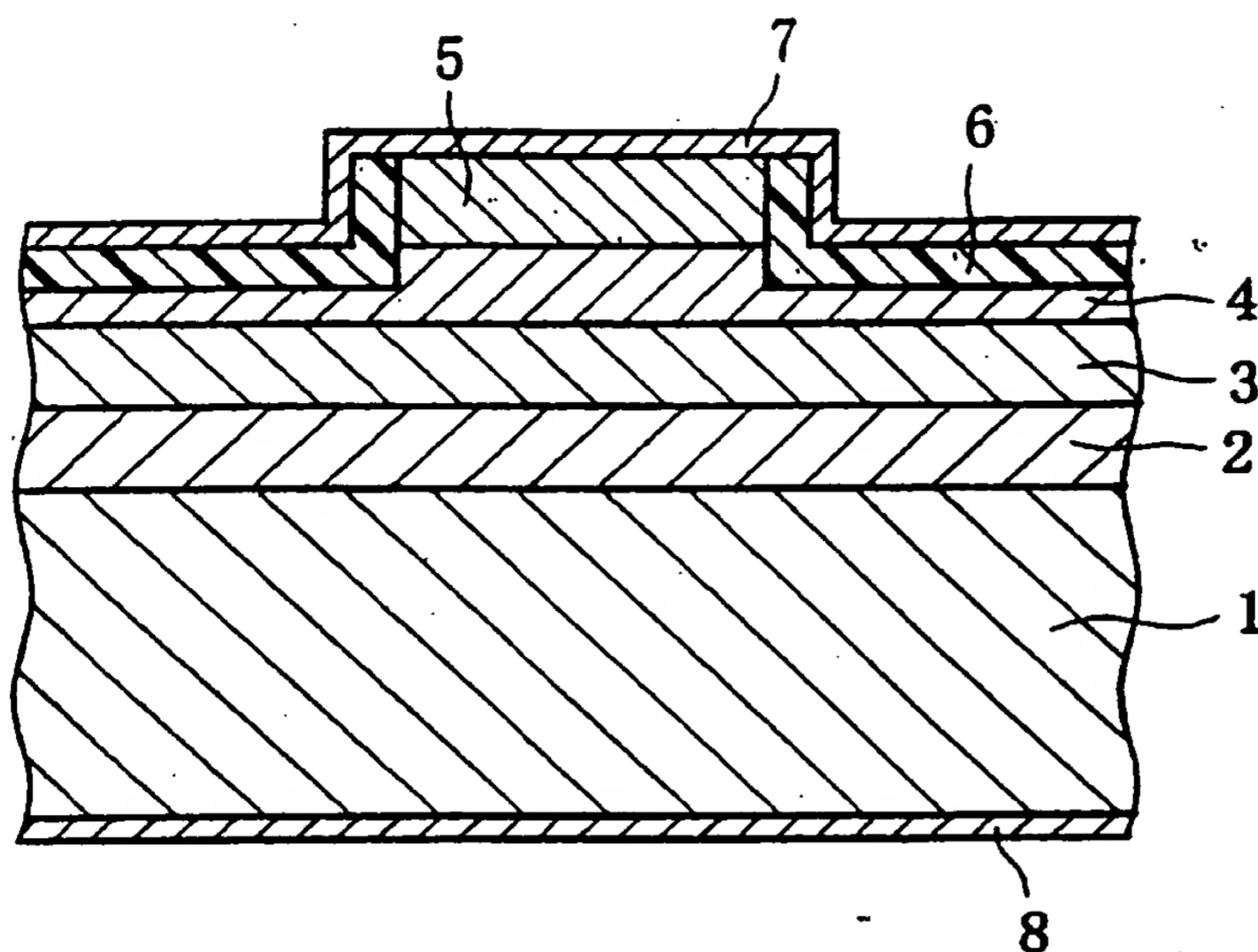
[FIG. 3]



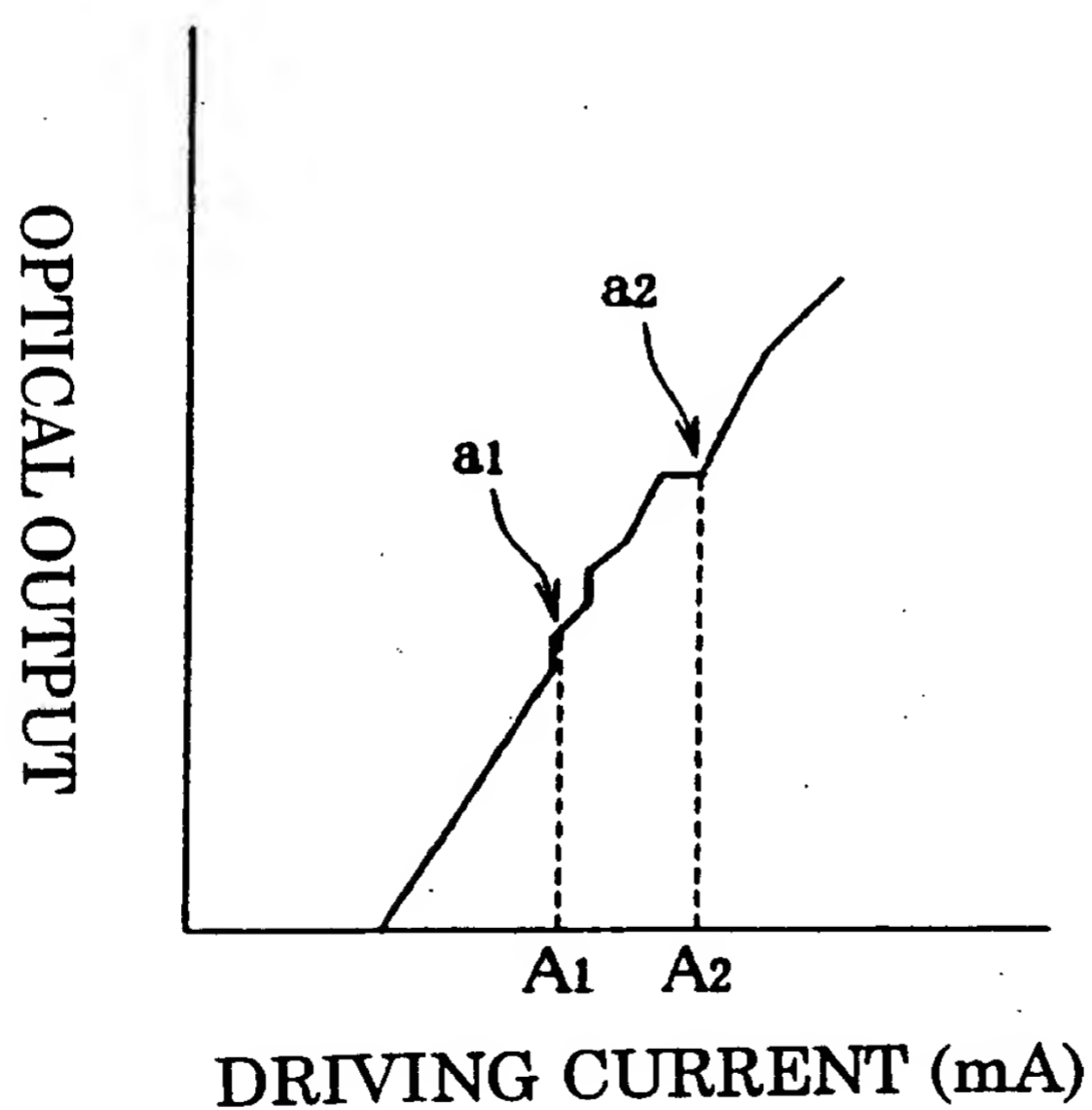
[FIG. 4]



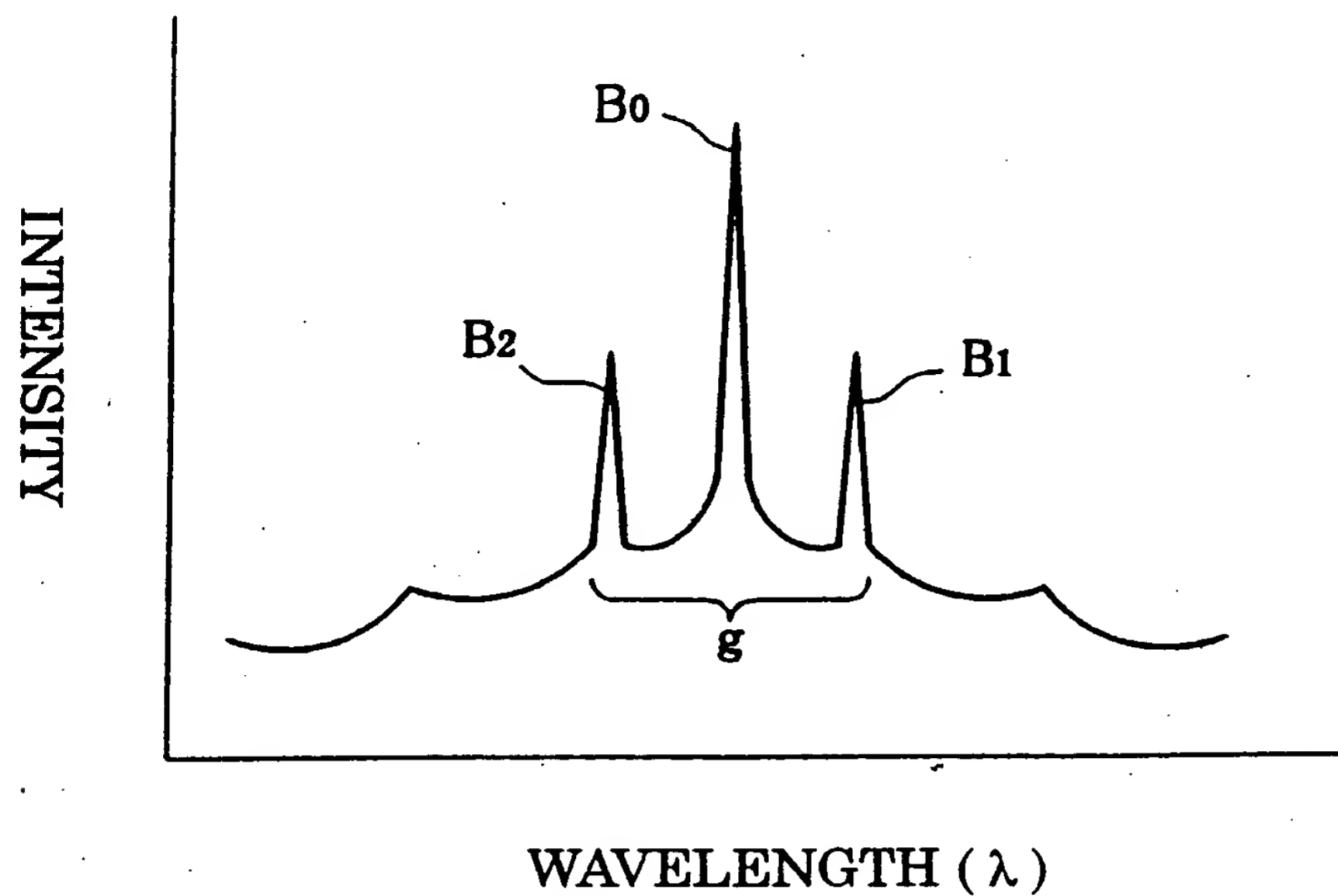
[FIG. 5]



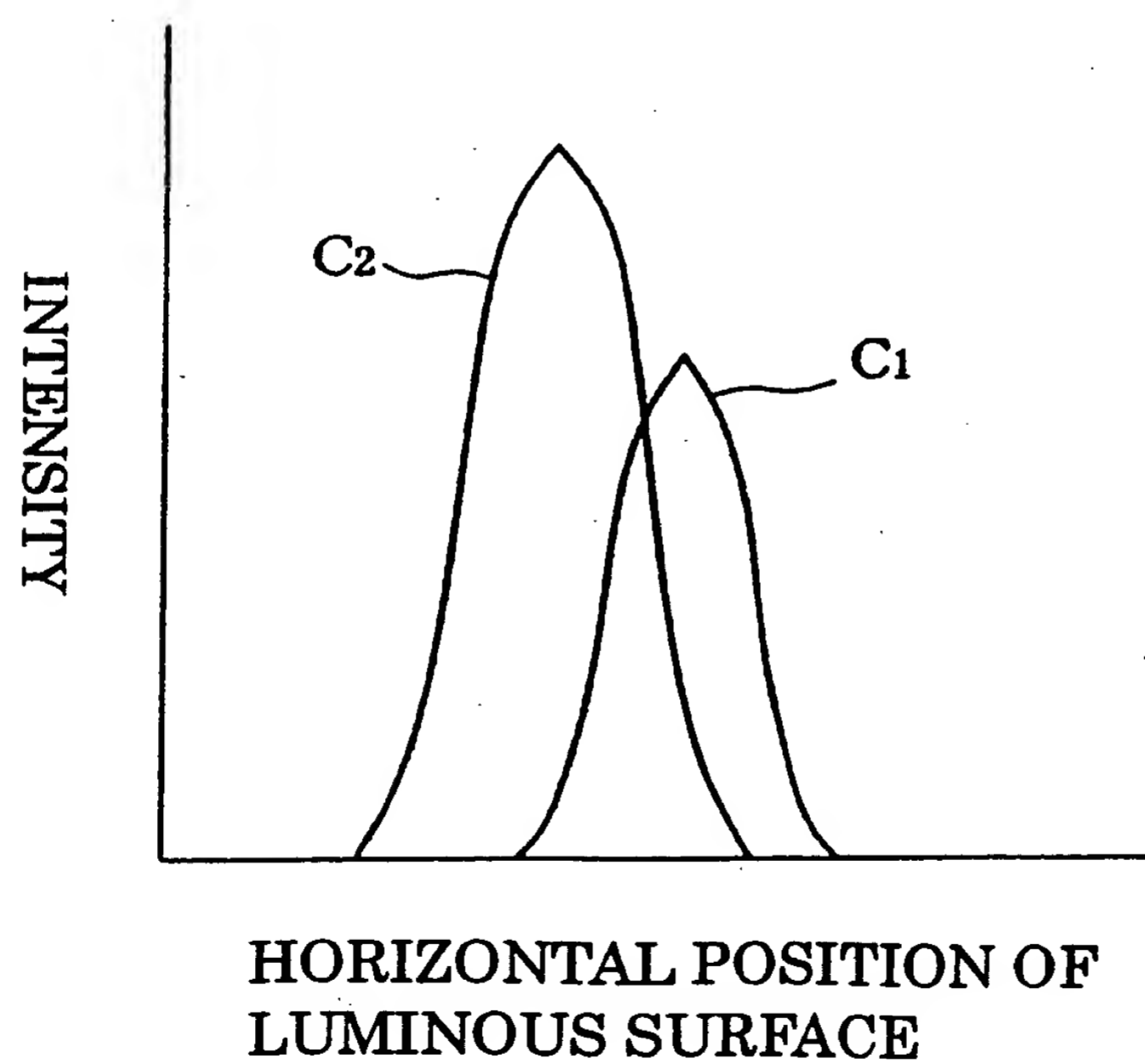
[FIG. 6]



[FIG. 7]



[FIG. 8]



OCT 28 2002  
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[Name of Document] Abstract

[Summary]

[Purpose] To provide a semiconductor laser device of a gain waveguide type having a large kink current, maintaining a linearity of a current-optical output characteristic, and useful as a pumping light source for an optical fiber amplifier.

[Means to accomplish the purpose] The semiconductor laser device oscillates within a wavelength band of  $1.1\text{ }\mu\text{m}$  or less and has a semiconductor laminated structure including an active layer formed of a quantum well structure, a low-reflection film 9 formed on one end face  $S_1$  of the structure, and a high-reflection film 10 formed on the other end face  $S_2$ . A cavity length (L) is  $1,200\text{ }\mu\text{m}$  or more.

[Selected Figure] FIG. 4